BROOKE CUTTING TOOLS

MILLING CUTTERS

USER GUIDE

BROOKE TECHNICAL SERVICES

This handbook is intended to help you get maximum performance from BROOKE cutting tools.

Whilst the information covers most common uses and problems it is not possible to deal with every situation. Our trained sales representatives are available to further assist and advise, fully backed up by factory technical services.

FULL SPECIFICATIONS IN BROOKE CATALOGUES

Brooke Cutting TOOLS Ltd is a world class manufacturer producing precision cutting tools to international standards and specifications which include British Standard, DIN, ISO, ANSI and JIS. Full details of specifications are listed in our catalogues which are available from leading Industrial Distributors or directly from the Brooke factory.

PRODUCT RANGE
STANDARDS & SPECIALS

The BROOKE range consists of nearly 13 000 standard items and we have a cutting tool available for almost every application. Sometimes a special tool is needed and our product engineers at the BROOKE factory can design a special purpose tool to do the job. These can also be manufactured to customers' specifications or to a sample.

CONTENTS

CONTENTS (cont.)

IF YOU CANNOT FIND AN ANSWER TO YOUR PROBLEM IN THIS BOOKLET PLEASE CONTACT THE BROOKE FACTORY.

CUTTING TOOL MATERIALS

Brooke cutting tools are manufactured from the finest steel available. The heat treatment process is controlled by our Metallurgical laboratory using advanced computerised and electronic instrumentation. High Speed Steel contains various elements such as Molybdenum, Tungsten, Cobalt and Vanadium and must be specially heat treated to produce the ideal combination of strength, toughness and wear resistance.

BROOKE products are manufactured from one of the following High Speed Steels depending on the product and application.

	C	Cr	W	Mo	V	Co	Hardness (HRC)
M2	0.9	4	6	5	2	-	63 - 65
M35	0.9	4	6	5	2	5	64 - 66
M42	1.1	4	1.5	9.5	1	8	66 - 68.5(70)
M9V	1.25	4.2	3.5	8.5	3.0	-	64 - 66

M2 is the standard High Speed Steel and is used where toughness is important, together with a good standard of wear resistance and red hardness.

M35 is a development of M2 and contains 5% cobalt which gives improved hardness, wear resistance and red hardness. It may be used when cutting higher strength materials.

M42 can be heat treated to very high hardness levels of up to 70 HRC (1 000 HV) although normally a slightly lower figure will be employed to retain toughness. This steel is ideal for machining higher strength materials and work hardening alloys such as stainless steels, nimonic alloys etc. Despite its high hardness, M42 has good grindability characteristics due to lower vanadium content.

M9V material is mainly used in the manufacture of machine taps because of its good wear resistance, good grinding capabilities, high hardness and excellent toughness.

Cutting tools may shatter
eye protection should be worn

SURFACE TREATMENTS

Bright Finish
A bright finish tool has no surface treatment and is suitable for general purpose use.

Blue Finish
A blue finish is achieved by steam tempering - a thermal process which imparts a non-metallic surface to the tool. This surface is porous and by absorbing lubricant, helps prevent rusting, reduces friction and cold welding, resulting in increased tool life.
Steam tempered products can successfully be used at slightly increased machining rates or on more difficult to machine materials.

Gold Oxide
This is a metallic brown coloured surface treatment achieved by a low temperature temper and is normally only used on cobalt products for identification purposes.

Nitriding
Nitriding imparts a hard surface to the tool and is used for prolonging tool life and machining difficult to machine materials. Because nitriding makes the edge more brittle, care must be exercised in the type of application.
Nitrided tools are normally also steam tempered.

Titanium Nitride Coating (TiN)
TiN coating is a very hard, gold coloured surface coating a few microns thick which is applied by means of a complex process, called Physical Vapour Deposition (PVD), by advanced modern equipment. The coating is non-metallic and therefore reduces cold welding.
In certain applications increased speed and feed rates can be achieved because of:

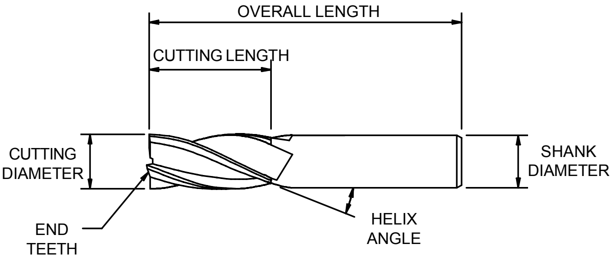
(a) The hardness of the coating.
(b) The reduction in cutting force required due to a decrease in friction between the tool and the workpiece.

Tool performance will deteriorate after re-sharpening.

TiCN (Titanium Carbonitride)
The addition of carbon to TiN results in a significant increase in the hardness of TiCN over TiN. TiCN also has a much lower coefficient of friction which enhances the surface finish of components machined with TiCN coated tools, higher productivity can be achieved on a wide range of materials but, in particular stainless steel, titanium and nickel based alloys.

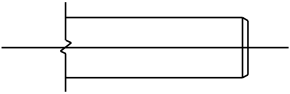
TiALN (Titanium Aluminium Nitride)
In addition to a higher hardness than both TiN and TiCN the aluminium in the coating imparts a much greater oxidation stability. This is as a result of a very thin film of (Aluminium Oxide) being formed on the surface of the TiALN. The film is self repairing, leading to additional increased service life. These improvements allow the coating to withstand much higher temperatures which in turn allows increased cutting conditions, especially useful when machining Cast Iron and tough steels.

END MILL NOMENCLATURE



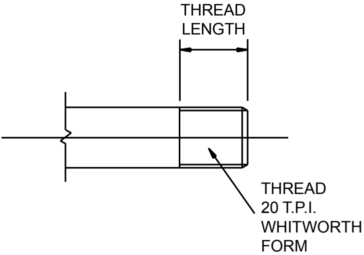
Shank Options

Plain Shank
Tolerance h7 on metric shank diameter (see page 49 for tolerance tables)



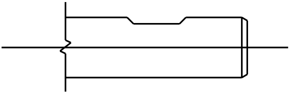
Threaded Shank

Tolerance h8 on metric / Fractional shank diameter



Flatted Shank

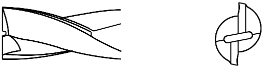
Tolerance h6 on metric shank diameter (see page 49 for tolerance tables



Typical End Mill Options

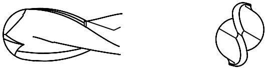
Two Flute End Mill

Tolerance e8 on cutting diameter (see page 49 for tolerance tables)



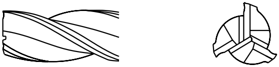
Ball Nose End Mill

Tolerance e8 on cutting diameter (see page 49 for tolerance tables)



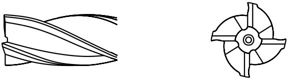
Three Flute End Mill

Tolerance e8 on cutting diameter (see page 49 for tolerance tables)



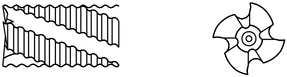
Multi-Flute End Mill

Tolerance js14 on cutting diameter (see page 49 for tolerance tables)



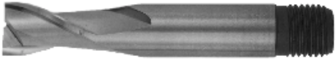
Roughing End Mill

Tolerance js 16 on cutting diameter (see page 49 for tolerance tables)



END MILL APPLICATIONS

Two and Three Flute End Mills

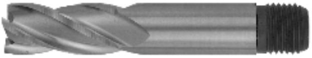


Two and three flute end mills are shank type cutters with peripheral teeth and end teeth of the plunging type. Intended for general purpose use, they have right hand cutting, right hand helical teeth; they are used on keyway and closed slotting operations where the close minus tolerance of the cutting diameter allows slot widths to be produced in one pass. These cutters are also extensively used when profiling and end milling aluminium alloys, due to the greater chip space required by this material.

Ball Nose Two Flute End Mills

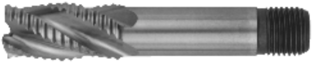
Ball nosed two flute end mills are manufactured to the same tolerances as the normal two flute end mill, and have a centre cutting ball end. They are used extensively in die making for cutting fillets, radiused slots, pocketing etc. These cutters have right hand cutting, right hand helical teeth.

Multi-Flute End Mills



Multi-flute end mills are shank type cutters with peripheral teeth and end teeth of the both plunging and non-plunging type. Designed for general purpose use they have right hand cutting, right hand helical teeth, and are used in stepping and profiling applications. They can also be used on slots where the plus tolerance of the cutting diameter is not critical.

Roughing End Mills



Shank type cutters with right hand cutting, right hand helical teeth on the periphery with roughing profile and with heavy duty end teeth. These cutters are robust and durable even under heavy cutting conditions on a wide range of materials. They are intended for rapid and heavy rates of stock removal where surface finish is of lesser importance. Available in coarse and fine pitch knuckle form and flat crest type.

HINTS FOR SUCCESSFUL END MILL USAGE

It is assumed that the workpiece clamping and machine size and power are adequate for the intended operation.

Always select the most suitable tool for the job on hand; a few minutes spent on selection can save hours of machining. Use roughing end mills when removing large amounts of stock; two or three flute end mills for deep slotting applications, for edge cutting and espically when machining light alloys. Use multi-flute end mills for edge cutting as well as for light finishing cuts.

Use threaded shank or flatted shank cutters where heavy stock removal and high tooth loads are involved. Plain shank cutters are particularly suitable for quick change CNC applications and for pre-setting off the machine.

Where possible check workpiece condition and hardness.

Check chucks and collects regularly ensuring that they are in good condition. Always clean cutter shanks and collets prior to assembly. Check that cutters are running true.

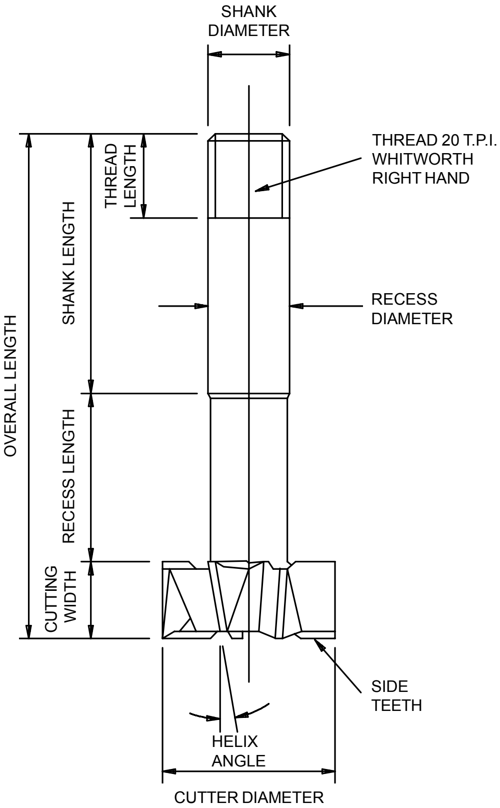
The most likely cause of cutter run-out is damaged chucks and collets.

Maintain cutters in a sharp condition to ensure maximum stock removal, surface finish and maximum power requirement.

Re-sharpen immediately when signs of wear are visible, since regrinding is then a relatively quick operation requiring little stock removal and with resulting increase in tool life. (See page 51 for resharpening details). Cutter storage is of paramount importance due to the brittle nature of the hardened cutting edges of all cutting tools. Poor storage often causes damage such as chipping of the cutting edges and breakage of corners, resulting in a tool which is useless. As in all machining operations cleaniless is essential.

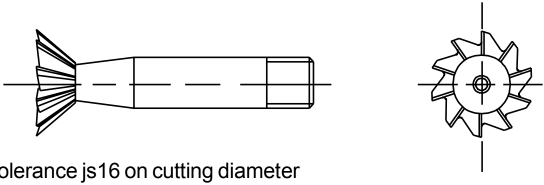
The best machining results are produced by cutters operating at the correct speed and feed to suit the material being worked. (See page 30 for technical data.)

SHANK CUTTER NOMENCLATURE



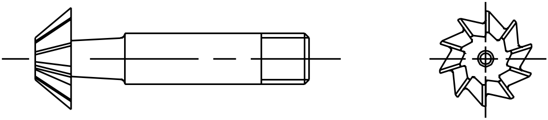
Types of shank cutters

Dovetail Cutter



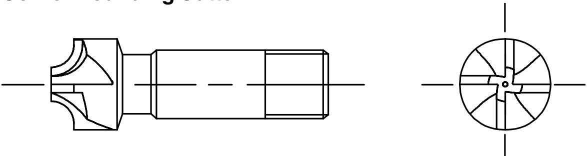
Tolerance js16 on cutting diameter
(see page 49 for tolerance tables)

Inverted Dovetail Cutter



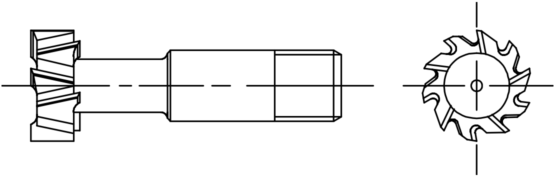
Tolerance js16 on cutting diameter
(see page 49 for tolerance tables)

Corner Rounding Cutter



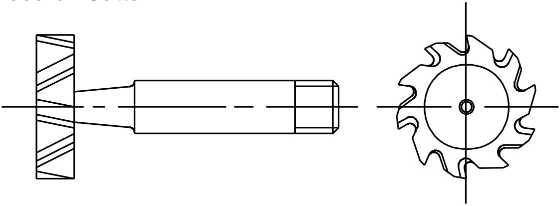
Tolerance H11 on radius and js14 on cutting tip
(see page 49 for tolerance tables)

T-Slot Cutter



Tolerance d11 on metric cutting diameter and width
Tolerance h12 on fractional cutting diameter and width
(see page 49 for tolerance tables)

Woodruff Cutter



Tolerance h11 on metric cutting diameter and e8 on width
(see page 49 for tolerance tables)

Tolerance on fractional diameter is

size	+0,381
	+0,127

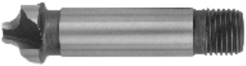
and on width is

size	+0,000
	- 0,025

Dovetail Cutters

These angle cutters have right hand cutting straight teeth and non-plunging end teeth. They are used wherever dovetails or angles are required and are available in a range of angles and diameters.

Corner Rounding Cutters



Straight tooth cutters with right hand cutting teeth. Intended to produce a true convex up to 90° of arc.

T-Slot Cutters

Shank type cutters with right hand cutting alternate helical peripheral teeth as well as teeth on either face. Intended for opening out existing slots to form the T-slots used extensively on machine tables. They are produced in a range of diameters and widths to allow clearance on a standard range of bolt head sizes.

Woodruff Cutters

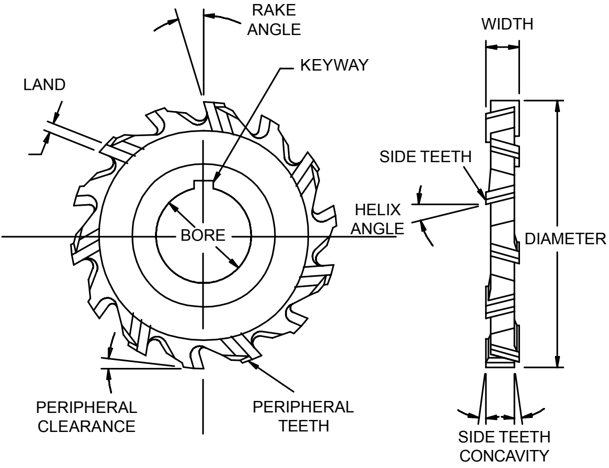
Shank type cutters with right hand cutting alternate helical peripheral teeth. Available in a range of diameters and widths. Designed to produce slots to suit standard woodruff keys.

HINTS FOR SHANK CUTTER USAGE

(See page 12 for hints on end mill usage)

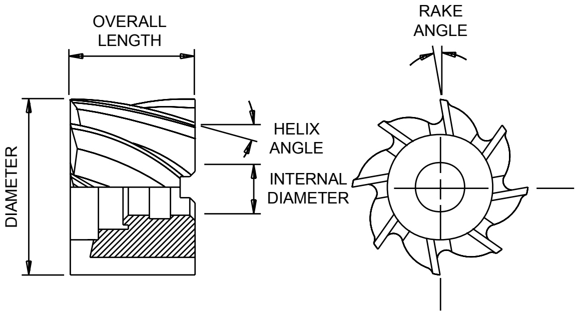
SIDE AND FACE CUTTER NOMENCLATURE

Side and Face Cutter- (Staggered Tooth shown)



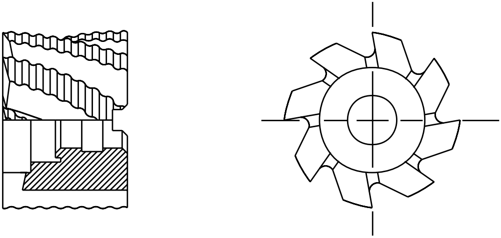
Tolerance js16 on metric cutting diameter and k11 on width (see page 49 for tolerance tables)

Plain Form



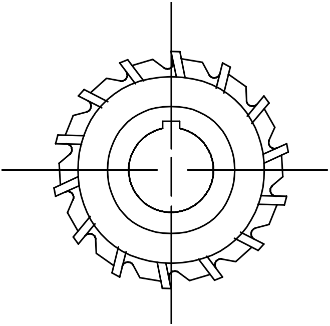
See page 24 for application.

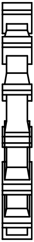
Roughing Form



See page 24 for application.

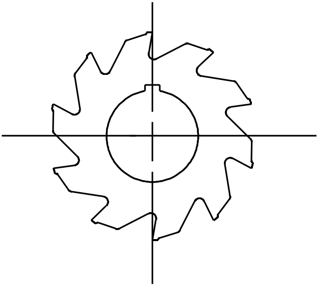
Side and Face Cutter- Straight Tooth

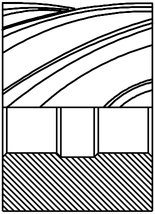




Tolerance js16 on metric/fractional cutting diameter and k11 on metric/ fractional width
(see page 49 for tolerance tables)

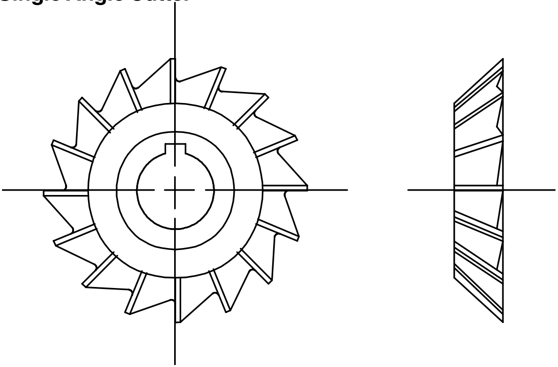
Cylindrical Cutter





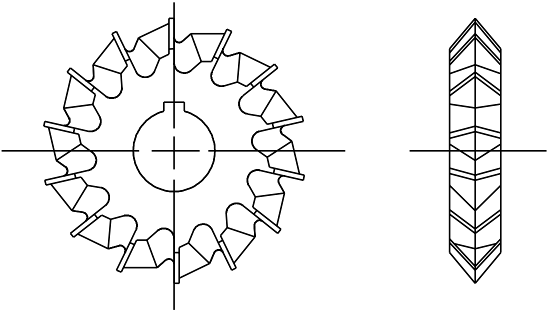
Tolerance js16 on cutting diameter and width
(see page 49 for tolerance tables)

Single Angle Cutter



Tolerance js16 on cutting diameter and js14 on width
(see page 49 for tolerance tables)

Double Angle Cutter



Tolerance js16 on cutting diameter and width
(see page 49 for tolerance tables)

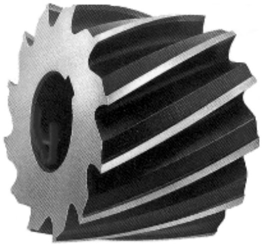
Staggered Tooth Side and Face Cutters

As the name suggests, side and face cutters have teeth on the periphery as well as on the sides, Designed with rugged alternate helical teeth, these cutters offer optimum performance when used for deep slotting with rapid stock removal; the cutting action of the alternate helical teeth combined with the coarse pitched side teeth giving excellent qualities of smooth cutting, efficient stock removal and good surface finish.

Straight Tooth Side and Face Cutters

Intended for light cuts and shallow slotting operations, the straight tooth side and face cutter is often used in a straddle milling function where two parallel surfaces are machined simultaneously. It is considered to be a compromise tool due to the reduced cutting action of its straight teeth, which cause greater shock when meeting the workpiece than cutters with helical teeth.

Cylindrical Cutters

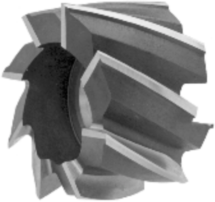


Intended for medium/light surfacing cuts these helical cutters offer the benefits of shock reduction combined with a good cutting action.

Angle Cutters

Produced with light duty straight teeth these cutters are used mainly for cutting dovetails, serrations and angled slots on less difficult materials.

Shell End Mills

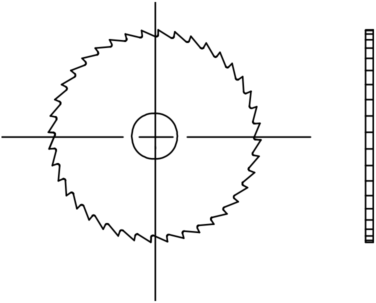


With helical peripheral teeth these cutters fillthe gap between normal shank cutters and the much larger facing cutters,this cuttter is better suited to light/medium cuts in a facing or stepping operation with its plain bore.

Shell End Mill (Roughing)

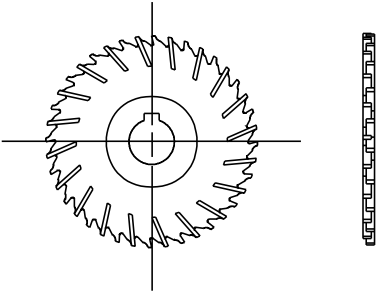
As the name implies, these cutters with their helical teeth and roughing profile are particularly efficient in areas where large volumes of stock must be removed at high speed and where tough materials are to be worked.

Slitting Saw - Plain



Tolerance js16 on cutting diameter and js10 on width
(see page 49 for tolerance tables)

Slitting Saw - Side Chip Clearance



Tolernace js16 on cutting diameter and js10 on width
(see page 49 for tolerance tables)

SLITTING SAW APPLICATIONS

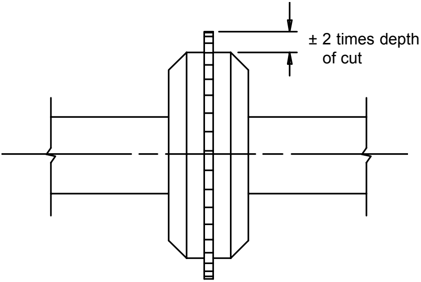
Slitting Saw - Plain

Intended for shallow cutting-off operations, these saws have straight teeth on the periphery and are tapered on width towards the bore to prevent binding. They are available in either coarse or fine pitch to suit the type and section of materials to be cut.

Slitting Saws - Side Chip Clearance

Intended for optimum production of deep narrow slots and for sawing operations, these saws have alternate helical teeth on the periphery combined with side teeth to ensure efficient stock removal, clean cutting action, and good surface finish.

HINTS FOR SUCCESSFUL SLITTING SAW USAGE



It is recommended that side plates be used with slitting saws.

HINTS FOR SUCCESSFUL ARBOR MOUNTED CUTTER USAGE

Some of the many factors governing efficient use of bore cutters are:-

1) Condition of machine
2) Machine power available
3) Machine capacity
4) Nature of the workpiece

Attention should be given to these factors prior to commencement. When using arbor mounted cutters the following points should be observed:-

Taper drive of arbor should be in good condition and fit correctly into machine drive.

Arbor and bushes should be kept in good and clean condition; dirty bushes cause run-out of cutters.

Arbors should be oiled and carefully stored when not in use; bent arbors are useless and expensive to replace.

Cutters should run true to prevent overloading of one or two teeth and extensive regrinding later.

Fit the cutter as closely as possible to the machine column with a support as near to the cutter as the workpiece will allow.

Running bushes and support bearings should be kept clean and in good running condition, particularly with regard to the bush faces. Lack of support will cause damage to the cutter and the workpiece. Always use correct lubricants.

Workpiece clamping should be rigid and able to withstand the forces acting upon it under the action of the cutter.

Select correct speeds and feeds for the cutter in use and the nature of the workpiece material and the size of the cut to be taken.

Use recommended coolants and direct flow to the point of cutting. Consult the coolant suppliers for specific recommendations. Adequate cooling is essential to prevent overheating of the cutter and failures associated with overheating.

Always use drive keys between the cutter and the arbor; friction between the cutter and the arbor bushes is seldom sufficient when cutters are under correct load.

Never force a cutter onto a arbor or over an ill-fitted key. Protect your hands by wrapping the cutter in a soft material when fitting or removing it from the arbor.

Due to the brittle nature of hardened tool steels it is not advisable to "remove" a cutter with a mallet once it has been tightened onto the arbor.

Maintain cutters in sharp condition. Regrind as soon as wear becomes apparent.

Store cutters carefully when not in use, using a light film of oil to prevent rusting.

Cleanliness of cutters and arbors is essential.

Use helically fluted cutters wherever possible to minimise shock as teeth contact the workpiece.

CUTTER TECHNICAL DATA

MATERIAL TYPE	GRADE	HARDNESS HB	TENSILE STRENGTH N / mm²
CARBON STEEL	FREE CUTTING	150	510
	0.3 to 0.4% Carbon	170	580
	0.3 to 0.4% Carbon	248	830
	0.4 to 0.7% Carbon	206	675
	0.4 to 0.7% Carbon	286	970
ALLOY STEEL		248	833
		330	1137
		381	1265
STAINLESS STEEL	Martensitic: Free Cutting	248	833
	Std. Grade	248	833
	Austenitic: Free Cutting	As Supplied	
	Std. Grade		
NIMONIC ALLOYS	Wrought	300	1030
	Cast	350	1200
TITANIUM	Titanium Comm: Pure	170	510
	Titanium Comm: Pure	200	660
	Titanium Comm: Pure	275	940
	Titanium Alloyed	340	1170
	Titanium Alloyed	350	1200
	Titanium Alloyed	380	1265
TOOL STEEL	HSS Standard Grades	225	735
	HSS Cobalt Grades	250	830
	Hot Working Steel	250	830
	Cold Working Steel	250	830
CAST IRONS	Grey, Malleable	240	800
	Hardened	330	1137

PERIPHERAL SPEED RANGE Refer to explanatory notes on page 32, 33				† CUTTING ANGLES		
TYPE *A	**TYPE *B**	**TYPE *C**	**TYPE *D**	**PRIMARY CLEARANCE**	**SECONDARY CLEARANCE**	**RADIAL RAKE**
30-40 24-32 18-25 24-32 16-25	28-40 24-32 18-25 24-32 16-20	24-32 20-26 14-20 20-26 12-20	30-40 24-32 18-25 24-32 16-25	8° - 20°	Add 10° to primary	9° - 14°
16-20 12-18 9-15	16-20 12-18 8-14	12-16 10-15 8-12	16-20 10-16 8-12	8° - 20°	Add 10° to primary	9° - 14°
10-20 5-10 10-20 5-10	12-16 5-10 12-16 5-10	8-15 4-8 8-15 4-8	10-20 5-10 10-20 5-10	8° - 20°	Add 10° to primary	9° - 14°
4-8	5-10	3-7	4-8	8° - 20°	Add 10° to primary	9° - 14°
7-12	5-12	5-10	7-12	8° - 20°	Add 10° to primary	9° - 14°
10-20 10-16 10-16 10-16	10-20 10-20 10-16 10-16	8-15 8-13 8-13 8-13	10-20 10-16 10-16 10-16	8° - 20°	Add 10° to primary	9° - 14°
16-20 12-16	16-20 10-14	12-16 10-12	20-28 16-22	8° - 20°	Add 10° to primary	9° - 14°

cont on page 32

CUTTER TECHNICAL DATA (cont)

MATERIAL TYPE	GRADE	HARDNESS HB	TENSILE STRENGTH N / mm²
ALUMINIUM ALLOYS	Wrought Wrought Cast	55 110 100	
COPPER ALLOYS	Brass : Free Cutting Low Leaded Bronze: Silicon Manganese Aluminium Phospor Copper	As Supplied	
PLASTICS		As Supplied	

Explanatory Notes

***Cutter types**

TYPE	CUTTER RANGE
A	End mills (2, 3 & Multi-Flute) T - Slot Cutters Dovetail & Inverted Dovetail Cutters Woodruff Cutters Corner Rounding Cutters
B	Side and Face Cutters Single and Double Angle Cutters Slitting Saws
C	Shell End Mills - Plain Tooth

PERIPHERAL SPEED RANGE Refer to explanatory notes on page 32, 33				† CUTTING ANGLES		
TYPE *A	**TYPE *B**	**TYPE *C**	**TYPE *D**	**PRIMARY CLEARANCE**	**SECONDARY CLEARANCE**	**RADIAL RAKE**
200-1500	120-180	50-180		10° - 20°	Add 10° to primary	20° - 28°
100-250	100-180	50-100				
40-100	50-70	30-80				
40-70	35-45	30-60		8° - 20°	Add 10° to primary	9° - 14°
50-80	45-70	40-65				
40-70	35-45	30-60				
25-45	20-40	20-35				
15-25	15-25	12-20		8° - 20°	Add 10° to primary	9° - 14°
15-25	15-25	12-20				
40-70	35-45	30-60		10° - 20°	Add 10°	20° - 28°
50-200	50-200			10° - 20°	Add 10° to primary	9° - 14°

***Cutter types** (cont)

TYPE	CUTTER RANGE
D	Shell End Mills - Roughing
Note:	For Roughing End Mills see page 11.

† Cutting Angles

Use higher angles for smaller diameters, reducing proportionately for larger diameters.

END MILLS: Feeds Per Tooth Sz (mm)

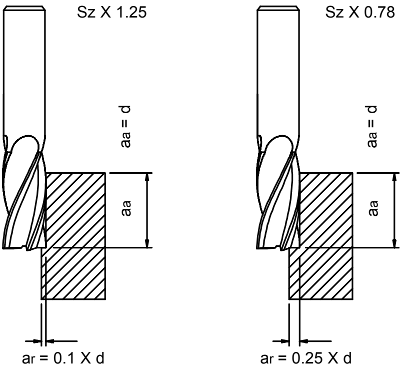


Table Shows Sz Values

End Mill	Carbon Steels	Alloy Steels	Stainless Steels	Nimonic Alloys	Titanium
3	0.010	0.010	0.010	0.008	0.010
4	0.015	0.015	0.015	0.012	0.015
5	0.018	0.018	0.018	0.014	0.018
6	0.022	0.022	0.022	0.018	0.022
8	0.030	0.030	0.030	0.024	0.030
10	0.036	0.036	0.036	0.029	0.036
12	0.044	0.044	0.044	0.036	0.044
14	0.051	0.051	0.051	0.040	0.051
16	0.058	0.058	0.058	0.046	0.058
18	0.065	0.065	0.065	0.052	0.065
20	0.073	0.073	0.073	0.058	0.073
22	0.080	0.080	0.080	0.064	0.080
25	0.090	0.090	0.090	0.072	0.090
28	0.102	0.102	0.102	0.081	0.102
30	0.110	0.110	0.110	0.088	0.110
32	0.116	0.116	0.116	0.092	0.116
35	0.130	0.130	0.130	0.104	0.130
40	0.130	0.130	0.130	0.104	0.130
50	0.130	0.130	0.130	0.104	0.130

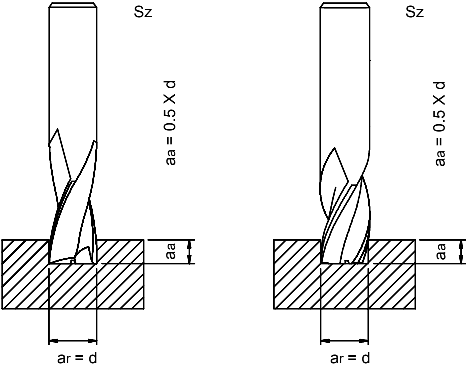


Table Shows Sz Values

Tool Steels	Cast Irons	Manganese Steels	Aluminium Alloys	Copper Alloys
0.009	0.010	0.008	0.013	0.013
0.013	0.016	0.012	0.019	0.019
0.016	0.022	0.014	0.023	0.023
0.020	0.028	0.018	0.028	0.028
0.027	0.036	0.024	0.039	0.039
0.032	0.040	0.029	0.046	0.046
0.040	0.045	0.036	0.057	0.057
0.046	0.056	0.040	0.066	0.066
0.052	0.064	0.046	0.075	0.075
0.058	0.070	0.052	0.085	0.085
0.065	0.080	0.058	0.092	0.092
0.072	0.088	0.064	0.104	0.104
0.080	0.095	0.072	1.117	0.117
0.091	0.110	0.081	0.132	0.132
0.100	0.120	0.088	0.143	0.143
0.104	0.127	0.092	0.150	0.150
0.117	0.142	0.104	0.170	0.170
0.117	0.142	0.104	0.170	0.170
0.117	0.142	0.104	0.170	0.170

ROUGHING END MILLS:
Peripheral Speed (m/min)
Feed Per Tooth   Sz (mm)

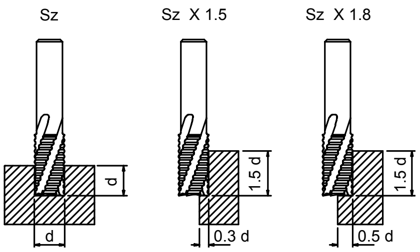


Table Shows Sz Values

End Mill Size	Material Group			
	1	2	3	4
6	0.008	0.008	0.009	0.010
8	0.013	0.013	0.015	0.015
10	0.017	0.020	0.020	0.021
12	0.023	0.025	0.025	0.033
14	0.026	0.030	0.030	0.037
16	0.030	0.038	0.038	0.044
22	0.032	0.040	0.040	0.048
25	0.035	0.042	0.042	0.050
28	0.035	0.045	0.042	0.050
30	0.040	0.045	0.045	0.056
32	0.042	0.050	0.050	0.064
35	0.013	0.013	0.015	0.015
38	0.045	0.057	0.057	0.070
40	0.045	0.057	0.057	0.070
45	0.047	0.059	0.060	0.075
50	0.060	0.074	0.075	0.090

Peripheral Speeds		
Material Group	Material Types	Cutter Speed (m/min)
1	Steels up to 500N/mm² Malleble Cast Iron up to 120 HB	28 - 40
2	Steels of 500 - 800 N/mm² Non - Alloyed Tool Steels Pure Titanium	24 - 32
3	Steels of 800 - 1200 N/mm² Hot Working Steels Cast Iron of 120 - 180 HB	18 - 25
4	Stainless Steels Titanium Alloys (Annealed) Cast Iron of more than 180 HB	12- 18
5	Titanium Alloys (Hardened)	7 - 12
6	Brass and Bronze (Cast)	35 - 45
7	Brass and Bronze (Rolled)	45 - 70
8	Plastics and similar	200 - 250

Table Shows Sz Values			
Material Group			
5	6	7	8
0.013	0.008	0.006	0.006
0.020	0.012	0.009	0.009
0.030	0.017	0.013	0.012
0.037	0.024	0.016	0.013
0.047	0.026	0.021	0.015
0.053	0.033	0.024	0.019
0.060	0.038	0.025	0.022
0.063	0.040	0.028	0.025
0.065	0.040	0.028	0.025
0.068	0.040	0.030	0.028
0.080	0.044	0.036	0.035
0.020	0.012	0.009	0.009
0.086	0.048	0.040	0.035
0.090	0.048	0.040	0.038
0.094	0.048	0.042	0.040
0.119	0.060	0.052	0.047

SIDE AND FACE CUTTERS - Staggered Tooth: Feed Per Tooth (mm)

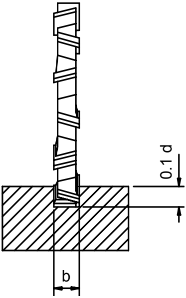


Table Shows Sz Values

Cutter Diameter	Cutter Width		Material Group		
			1	2	3
	over	to			
63	3	10	0.050	0.051	0.051
	10	18	0.052	0.054	0.054
80	4	12	0.063	0.063	0.070
	12	20	0.064	0.064	0.070
100	5	14	0.069	0.069	0.070
	14	25	0.070	0.069	0.070
125	7	16	0.077	0.078	0.080
	16	28	0.078	0.078	0.080
160	7	18	0.088	0.090	0.100
	18	32	0.090	0.090	0.190
200	8	18	0.093	0.093	0.194
	18	32	0.101	0.101	0.102
250	8	18	0.107	0.107	0.110
	18	32	0.105	0.105	0.106

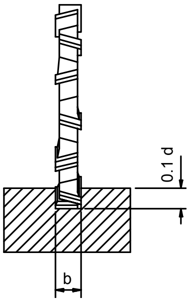


Table Shows Sz Values

Material Group				
4	5	6	7	8
0.050	0.051	0.050	0.046	0.020
0.052	0.053	0.052	0.048	0.020
0.063	0.063	0.063	0.056	0.020
0.063	0.063	0.063	0.056	0.020
0.070	0.070	0.070	0.062	0.020
0.070	0.070	0.070	0.070	0.020
0.078	0.080	0.080	0.080	0.020
0.078	0.080	0.080	0.080	0.020
0.090	0.090	0.090	0.090	0.020
0.090	0.090	0.090	0.090	0.020
0.093	0.094	0.093	0.093	0.020
0.102	0.102	0.101	0.101	0.020
0.108	0.110	0.108	0.108	0.020
0.104	0.105	0.104	0.104	0.020

SHELL END MILLS:
Feed Per Tooth (mm)

Plain Tooth

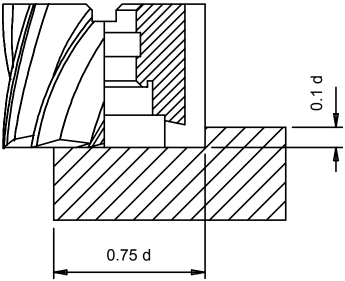


Table Shows Sz Values

Type	Cutter Diameter	Material Group		
		1	2	3
PLAIN	40	0.080	0.080	0.080
	50	0.080	0.080	0.080
	63	0.100	0.100	0.100
	80	0.100	0.100	0.100
	100	0.100	0.100	0.100
	125	0.100	0.100	0.100
	160	0.105	0.105	0.105
ROUGHING	40	0.060	0.060	0.060
	50	0.070	0.070	0.070
	63	0.075	0.080	0.070
	80	0.100	0.100	0.100
	100	0.110	0.110	0.110
	125	0.115	0.115	0.115
	160	0.120	0.120	0.125

Roughing Form

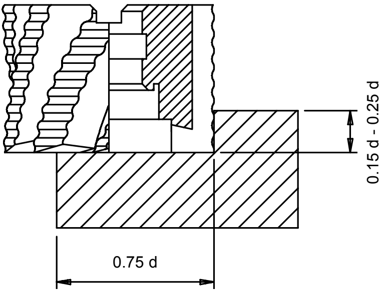


Table Shows Sz Values				
Material Group				
4	5	6	7	8
0.080 0.080 0.100 0.100 0.100 0.100 0.105	0.080 0.080 0.100 0.100 0.100 0.100 0.105	0.080 0.080 0.100 0.100 0.100 0.100 0.105	0.080 0.080 0.100 0.100 0.100 0.100 0.105	0.022 0.022 0.022 0.022 0.022 0.022 0.022
0.060 0.075 0.080 0.100 0.110 0.115 0.120	0.060 0.075 0.080 0.100 0.110 0.115 0.120	0.060 0.075 0.080 0.100 0.110 0.115 0.120	0.060 0.075 0.080 0.100 0.110 0.115 0.120	0.022 0.028 0.031 0.039 0.039 0.042 0.044

METRES PER MIN	5	10	20	30	40
Dia. mm					Revolutions
1.0	1591	3182	6364	9546	12728
2.0	795	1590	3182	4770	6360
3.0	530	1060	2120	3180	4240
4.0	398	795	1590	2385	3180
5.0	318	636	1272	1908	2544
6.0	265	530	1060	1590	2120
7.0	227	455	910	1365	1820
8.0	199	398	796	1194	1592
9.0	177	353	706	1059	1412
10.0	159	318	636	954	1272
11.0	145	289	578	867	1156
12.0	133	265	530	795	1060
13.0	122	245	490	735	980
14.0	114	227	454	681	908
15.0	106	212	424	636	848
16.0	100	199	398	597	796
18.0	89	177	354	531	708
20.0	80	159	318	477	636
22.0	73	145	290	435	580
24.0	67	133	266	399	532
26.0	61	122	344	366	488
28.0	57	144	228	342	456
30.0	53	106	212	318	424
35.0	45	91	182	273	364
40.0	40	80	160	240	320
45.0	35	70	140	210	280
50.0	32	64	128	192	256
63.0	25	50	100	150	200
75.0	21	42	84	126	168
100.0	16	32	64	96	128

TO rpm CONVERSION CHART

50	60	70	80	90	100

per Minute

15910	19092	22274	25456	28638	31820
7950	9540	11130	12720	14310	15900
5300	6360	7420	8480	9540	10600
3975	4770	5565	6360	7155	7950
3180	3816	4452	5088	5724	6360
2650	3180	3710	4240	4770	5300
2275	2730	3185	3640	4095	4550
1990	2388	2786	3184	3582	3980
1765	2118	2471	2824	3177	3530
1590	1908	2226	2544	2862	3180
1445	1734	2023	2312	2601	2890
1325	1590	1855	2120	2385	2650
1225	1470	1715	1960	2205	2450
1135	1362	1589	1816	2043	2270
1060	1272	1484	1696	1908	2120
995	1194	1393	1592	1791	1990
885	1062	1239	1416	1593	1770
795	954	1113	1272	1431	1590
725	870	1015	1160	1305	1450
665	798	931	1064	1197	1330
610	732	854	976	1098	1220
570	684	798	912	1026	1140
530	636	742	848	954	1060
455	546	637	728	819	910
400	480	560	640	720	800
350	420	490	560	630	700
320	384	448	512	576	640
250	300	350	400	450	500
210	252	294	336	378	420
160	192	224	256	288	320

Speed and Feed Formulae

$$v = \frac{D.\ \pi.\ rpm}{1000}$$

$$Sz = \frac{S^1}{rpm.Z}$$

$$rpm = \frac{V.\ 1000}{\pi.D}$$

$$Sn = \frac{S^1}{rpm}$$

$$S^1 = Sz.\ Z.\ rpm$$

$$V = \frac{a.\ b.\ S^1}{1000}$$

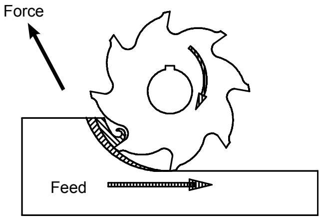
$$p = 3.1416$$

v	=	speed (m/min)
D	=	cutter diameter (mm)
rpm	=	revolutions/min
Sn	=	feed/revolution (mm)
S^1	=	feed/minute (mm)
Sz	=	feed/tooth (mm)
Z	=	number of teeth on cutter
V	=	chip volume (cm^3 /min)
a	=	depth of cut (mm)
b	=	length of cut (mm)

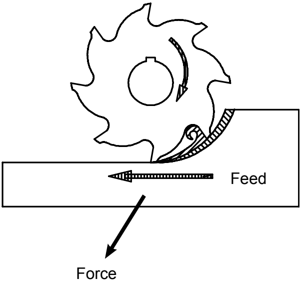
CLIMB OR CONVENTIONAL MILLING

From the very beginning of the milling process, it was found practical to always rotate the end mill in the opposite direction to the feed of the workpiece. This is termed conventional milling.

In conventional milling the end mill engages the workpiece at the bottom of the cut. The end mill teeth slide along until sufficient pressure builds up to break through the surface of the work. This sliding action under pressure tends to abrade the periphery of the end mill with resulting dulling. Also in horizontal conventional milling, the cutting action has a tendency to lift the workpiece, fixture and table from their bearings. In recent years, milling machines have been greatly improved through backlash elimination and greater rigidity so that climb milling is now possible. Climb milling improves surface finish and increases tool life.



Conventional Milling



Climb Milling

In climb milling the end mill rotates in the direction of the feed. The tooth meets the work at the top of the cut at the thickest portion of the chip. This provides instant engagement of the end mill with the workpiece producing a chip of definite thickness at the start of the cut without the rubbing action resulting from conventional milling. It further permits the gradual disengagement of the teeth and work so that feed marks are largely eliminated.

Climb milling will often provide better product finish, permit greater feed per tooth and prolong the cutter life per sharpening. It is particularly desirable to climb mill such materials as heat treated alloy steels and non-free machining grades of stainless steel for better tool life and to reduce work hardening. It is not recommended on material having a hard scale, such as cast or scaly forged surfaces, because abrasion would quickly ruin the cutting edges. Also some very soft steels do not lend themselves to climb milling because of their tendency to drag and tear.

Climb milling cannot be applied to every milling operation and should not be attempted if the material and the machine setup are not adapted to this type of milling.

PROBLEM SOLVING

Milling problems are often caused by one or more of the following factors, which should be carefully checked in a systematic and logical manner.

Speeds and Feeds
See page 30 for recommendations.

Coolants
Seek advice from your supplier.

Cutter Selection
Always select the correct type and quality of cutter to suit the application.

Arbors
Straightness/runout/size/wear/damage
Bushing-wear/damage.

Re-sharpening
Clearance angles. See page 51
Runout
Burning/overheating
Surface finish

Milling Machines
Slides and gib strips
Lead screws and nuts
Backlash elimination
Attachments
Defective workheads
Worn tailstocks
Worn centres

Workholding
Workdolder condition
Workholder suitability
Workholder alignment
Workholder rigidity

Workpiece Condition
Machine suitability
Material specifications
Material hardness
Material surface conditions
Machining characteristics

Cutter Holders
Collets
Chucks
Draw bars
Runout
Damage

TOLERANCES

Tolerances in μm = 1 micron (1/1000mm)

	DIAMETER OR WIDTH							
Tol.	3mm	3 to 6mm	6 to 10mm	10 to 18mm	18 to 30mm	30 to 50mm	50 to 80mm	80 to 120mm
d11	-20 -80	-30 -105	-40 -130	-50 -160	-65 -195	-80 -240	-100 -290	-120 -340
e8	-14 -28	-20 -38	-25 -47	-32 -59	-40 -73	-50 -89	-60 -106	-72 -126
h6	0 -6	0 -8	0 -9	0 -11	0 -13	0 -16	0 -19	0 -22
h8	0 -14	0 -18	0 -22	0 -27	0 -33	0 -39	0 -46	0 -54
h11	0 -60	0 -75	0 -90	0 -110	0 -130	0 -160	0 -190	0 -220
h12	0 -100	0 -120	0 -150	0 -180	0 -210	0 -250	0 -300	0 -350
js10	+20 -20	+24 -24	+29 -29	+35 -35	+42 -42	+50 -50	+60 -60	+70 -70
js14	+125 -125	+150 -150	+180 -180	+215 -215	+260 -260	+310 -310	+370 -370	+435 -435
js16	+300 -300	+375 -375	+450 -450	+550 -550	+650 -650	+800 -800	+950 -950	+1100 -1100
k11	+60 -0	+75 -0	+90 -0	+110 -0	+130 -0	+160 -0	+190 -0	+220 -0
H7	+10 0	+12 0	+15 0	+18 0	+21 0	+25 0	+30 0	+35 0
H11	+60 0	+75 0	+90 0	+110 0	+130 0	+160 0	+190 0	+220 0

DIFFICULT TO MACHINE MATERIALS

There are number of materials which are generally regarded as being difficult to machine. In general terms the material being worked is considered to be difficult when it does not respond readily to normal machining techniques. Among these “difficult’ materials are aluminium alloys, stainless steel and work hardening steels.

Aluminium Alloys require relatively high speeds and feeds. They respond best to cutters with few teeth and correspondingly wide chip spaces, and can be worked very effectively by using two flute end mills, which have the advantage of fewer teeth engaged in the cut. In many cases coolant may not be needed to cool the cutter although it is of benefit in lubricating and particularly in removing chips. Climb milling gives definite advantages and shows significant benefits where a good quality surface finish is needed. These materials can be worked quite effectively with regular tooling, although benefits would be obtained from custom tools in the event of large volume production being the norm.

Stainless Steels require lower speeds and higher feed rates and often benefits are obtained from using corner radii and chamfers. These materials respond well to the conventional cutting method but rigidity of machine and setup are critical. Light finishing cuts are to avoided but where necessary should be taken at a feed rate as high as possible to meet with surface finishing requirements. It is crucial that these materials be “worked”, and “rubbing” of the cutter against the workpiece should be avoided. Selection of speed and feed rates is of great importance. Coolant must be used in large volume and be directed at the cutting area. Benefits are often obtained from a higer coolant concentration or from using cutting oils.

Work Hardening Steels such as some stainless and manganese steels can be successfully machined by using the same techniques as described for stainless steels above.

RESHARPENING AND CARE OF MILLING CUTTERS

The productivity of a milling machine depends to a large degree on the efficiency of the milling cutter. Best results in both production and cutter life are obtained by sharpening cutters correctly and carefully, and by taking proper care in handling and storage. A correctly sharpened cutter requires less driving power, produces better quality work and gives longer service than an incorrectly or hastily sharpened cutter.

The following factors should be considered:-

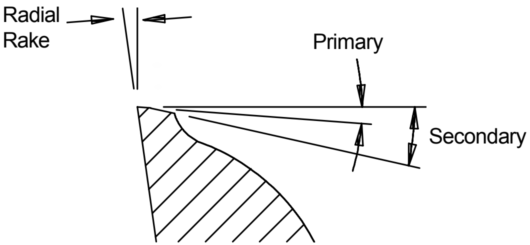
Correct handling and storage to prevent damage.

Restoration of the cutting edges to their original geometry using correct procedures.

Suitable wheel selection to ensure correct surface finish and stock removal. Consult wheel suppliers for specific recommendations.

Remember that milling cutters are precision tools and must be handled carefully. Damage due to incorrect handling or storage can be seen as a flaw upon the milled surface of a workpiece. Grinding should be needed only as a result of dulling due to use. Regrinding to remove damage caused by rough handling must be considered to be a wasted process which reduces the life of a cutter.

Correct clearance angles and radial rakes can be obtained from data given on page 30, 31 & 33.



GENERAL INFORMATION

INCH-MILLIMETER CONVERSION TABLE

	0" mm	1" mm	2" mm	3" mm
0		25.400	50.800	76.200
1/64	0.397	25.797	51.197	76.597
1/32	0.794	26.194	51.594	76.994
3/64	1.191	26.591	51.991	77.391
1/16	1.588	26.988	52.388	77.788
5/64	1.984	27.384	52.784	78.184
3/32	2.381	27.781	53.181	78.581
7/64	2.778	28.178	53.578	78.978
1/8	3.175	28.575	53.975	79.375
9/64	3.572	28.972	54.372	79.772
5/32	3.969	29.369	54.769	80.169
11/64	4.366	29.766	56.166	80.566
3/16	4.762	30.162	55.562	80.962
13/64	5.159	30.599	55.959	81.359
7/32	5.556	30.956	56.356	81.756
15/64	5.953	31.353	56.753	82.153
1/4	6.350	31.750	57.150	82.550
17/64	6.747	32.147	57.547	82.947
9/32	7.144	32.544	57.944	83.344
19/64	7.541	32.941	58.341	83.741
5/16	7.938	33.338	58.738	84.138
21/64	8.334	33.734	59.134	84.534
11/32	8.731	34.131	59.531	84.931
23/64	9.128	34.528	59.928	85.328
3/8	9.525	34.925	60.325	85.725
25/64	9.922	35.322	60.722	86.122
13/32	10.319	35.719	61.119	86.519
27/64	10.716	36.116	61.516	86.916
7/16	11.112	36.512	61.912	87.312
29/64	11.509	36.909	62.309	87.709
15/32	11.906	37.306	62.706	88.106
31/64	12.303	37.703	63.103	88.503

INCH-MILLIMETER CONVERSION TABLE (cont)

	0" mm	1" mm	2" mm	3" mm
1/2	12.700	38.100	63.500	89.900
33/64	13.097	38.497	63.897	89.297
17/32	13.494	38.894	64.294	89.694
35/64	13.891	39.291	64.691	90.091
9/16	14.288	39.688	65.088	90.488
37/64	14.684	40.084	65.484	90.884
19/32	15.081	40.481	65.881	91.281
39/64	15.748	40.878	66.278	91.678
5/8	15.875	41.275	66.675	92.075
41/64	16.271	41.671	67.071	92.471
21/32	16.668	42.068	67.468	92.868
43/64	17.066	42.466	67.866	92.266
11/16	17.462	42.862	68.262	93.662
45/64	17.859	43.859	68.859	94.859
23/32	18.256	43.656	69.056	94.456
47/64	18.653	44.053	69.453	94.853
3/4	19.050	44.450	69.850	95.250
49/64	19.447	44.847	70.247	95.647
25/32	19.844	45.244	70.644	96.044
51/64	20.241	45.641	71.041	96.441
13/16	20.638	46.038	71.438	96.838
53/64	21.034	46.434	71.834	97.234
27/32	21.431	46.831	72.231	97.631
55/64	21.828	47.228	72.628	98.028
7/8	22.225	47.625	73.025	98.425
57/64	22.622	48.022	73.422	98.282
29/32	23.019	48.019	73.019	99.019
59/64	23.416	48.816	74.216	99.616
15/16	23.812	49.212	74.612	100.012
61/64	24.209	49.609	75.009	100.409
31/32	24.606	50.006	75.406	100.806
63/64	25.003	50.403	75.803	101.203

APPROXIMATE HARDNESS AND TENSILE STRENGTH CONVERSIONS

HRB	HRC	HV	HB	TENSILE STRENGTH Tons inch²	TENSILE STRENGTH MPa or N/mm²
50	—	95	90	21	320
55	—	100	100	23	350
60	—	110	105	25	390
65	—	120	110	27	420
70	—	130	120	29	450
75	—	140	130	31	480
80	—	150	140	34	520
85	—	165	160	37	570
90	—	185	175	40	620
95	—	205	195	45	690
100	20	230	220	50	770
—	22	240	230	53	820
—	24	255	240	56	860
—	26	265	250	59	910
—	28	280	265	62	960
—	30	295	280	65	1000
—	32	310	290	68	1050
—	34	325	310	72	1110
—	36	345	325	75	1150
—	38	360	345	78	1200
—	40	380	365	83	1280
—	42	405	385	88	1360
—	44	425	405	92	1420
—	46	450	430	96	1480
—	48	480	455	102	1540
—	50	505	480	108	1670
—	52	545	—	112	1720
—	54	580	—	117	1800
—	56	615	—	122	1890
—	58	655	—	130	2000
—	60	695	—	135	2100
—	64	790	—	150	2320
—	66	855	—	163	2510
—	68	940	—	179	2770
—	70	1075	—	197	3030
—	75	1480	—	—	—
—	80	1865	—	—	—

HRB = Hardness Rockwell B
HRC = Hardness Rockwell C
HV = Hardness Vickers. Also DPN, VPN, DPH, VPH
HB = Hardness Brinell. Also BHN

Note:
These values should be treated as approximate only and are suitable for calculating speeds and feeds or for general information purposes. Do not use for treated high speed steel.

HARDNESS CONVERSION CHART FOR HIGH SPEED STEEL

HV30	HRC
736	59-3/4
741	60
746	60-1/4
752	60-1/4
757	60-1/2
763	61
769	61
775	61-1/4
780	61-1/2
786	61-3/4
792	62
798	62-1/4
804	62-1/2
810	62-3/4
817	63
823	63-1/4
829	63-1/2
836	63-3/4
842	64
849	64-1/4

HV30	HRC
856	64-1/2
862	63-3/4
869	65
876	65-1/4
883	65-1/2
890	66
897	66
905	66-1/2
912	67
919	67
927	67-1/4
934	67-1/2
942	68
950	68
958	68-1/2
966	68-1/2
974	69
982	69-1/2
990	69-1/2
999	70

Typical hardness

M2	823-876 HV30 - 63-65 HRC
M35	849-920 HV30 - 64-66 HRC
M42	897-966 HV30 - 66 - 68-1/2 HRC

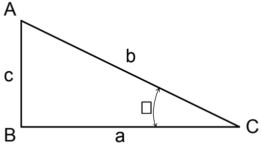
Depending on the nature of the tool these hardnesses may be varied, particularly in the case of special tools where different hardnesses may be specified.

Note:
Undue reliance should not be placed on a general conversion chart unless it has been tested for a particular material. The above chart applies specifically to High Speed Steel.

USEFUL FORMULAE

Trigonometry

Formulae for the solution of RIGHT ANGLED TRIANGLES

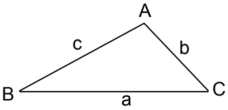


$$\text{Tan } \square = \frac{\text{opposite}}{\text{adjacent}} = \frac{c}{a}$$

$$\text{Sin } \square = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{c}{b}$$

$$\text{Cos } \square = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{a}{b}$$

Formulae for the solution of OBLIQUE ANGLED TRIANGLES



The Sine rule:

$$\frac{a}{\text{Sin A}} = \frac{b}{\text{Sin B}} = \frac{c}{\text{Sin C}}$$

The Cosine rule:

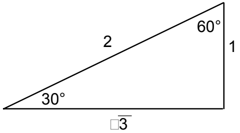
$a^2 = b^2 + c^2 - 2bc \text{ Cos A}$

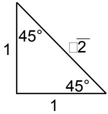
$b^2 = a^2 + c^2 - 2ac \text{ Cos B}$

$c^2 = a^2 + b^2 - 2ab \text{ Cos C}$

USEFUL VALUES IN TRIGNOMETRICAL RATIOS

For right angled triangles





ANGLES 30° - 45° - 60°

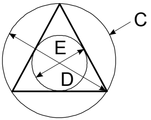
□	Tan □	Sin □	Cos □
30°	$\frac{1}{\square 3}$ = 0.577350	$\frac{1}{2}$ = 0.500000	$\frac{\square 3}{2}$ = 0.866025
45°	1	$\frac{1}{\square 2}$ = 0.707107	$\frac{1}{\square 2}$ = 0.707107
60°	$\square 3$ = 1.732051	$\frac{\square 3}{2}$ = 0.866025	$\frac{1}{2}$ = 0.500000

Useful formulae for Finding Dimensions of Circles, Squares, etc.

D is diameter of stock necessary to turn shape desired.
E is distance "across flats," or diameter of inscribed circle.
C is depth of cut into stock turned to correct diameter.

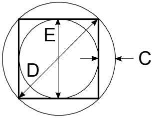
TRIANGLE

E	= side x 0.57735
D	= side x 1.1547 = 2E
Side	= D x 0.866
C	= E x 0.5 = D x 0.25



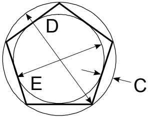
SQUARE

E	= side = D x 0.7071
D	= side x 1.4142 = diagonal
Side	= D x 0.7071
C	= D x 0.14645



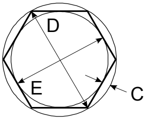
PENTAGON

E	= side x 1.3764 = D x 0.809
D	= side x 0.7013 = E x 1.2361
Side	= D x 0.5878
C	= D x 0.0955



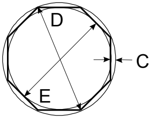
HEXAGON

E	= side x 1.7321 = D x 0.866
D	= side x 2 = E x 1.1547
Side	= D x 0.5
C	= D x 0.067



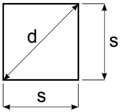
OCTAGON

E	= side x 2.4142 = D x 0.9239
D	= side x 2.6131 = E x 1.0824
Side	= D x 0.3827
C	= D x 0.038



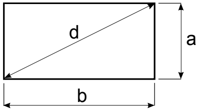
Areas of Plane Figures

SQUARE



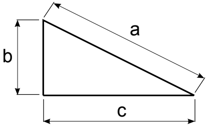
A = area
$A = \mathbf{S^2} = 1/2\, d^2$
$S = 0.7071d = \sqrt{A}$
$d = 1.414S = 1.414\sqrt{A}$

RECTANGLE



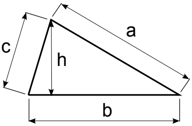
A = area
$A = ab = a\sqrt{d^2 - a^2} = b\sqrt{d^2 - b^2}$
$d = \sqrt{a^2 + b^2}$
$a = \sqrt{d^2 - b^2} = A \div b$
$b = \sqrt{d^2 - a^2} = A \div a$

RIGHT ANGLED TRIANGLE



A = area
$A = \frac{\mathbf{bc}}{\mathbf{2}}$
$a = \sqrt{b^2 + c^2}$
$b = \sqrt{a^2 - c^2}$
$c = \sqrt{a^2 - b^2}$

ACUTE ANGLED TRIANGLE



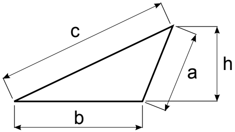
A = area

$$A = \frac{\mathbf{bh}}{\mathbf{2}} = \frac{b}{2}\sqrt{a^2 - \left(\frac{a^2 + b^2 - c^2}{2b}\right)^2}$$

if $S = \frac{1}{2}(a + b + c)$ then,

$$A = \sqrt{S(S - a)(S - b)(S - c)}$$

OBTUSE ANGLED TRIANGLE



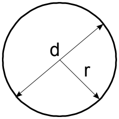
A = area

$$A = \frac{bh}{2} = \frac{b}{2}\sqrt{a^2 - \left(\frac{c^2 - a^2 - b^2}{2b}\right)^2}$$

if $S = \frac{1}{2}(a + b + c)$ then,

$$A = \sqrt{S(S - a)(S - b)(S - c)}$$

CIRCLE



A = area C = circumference

$A = \pi r^2 = 3.1416\, r^2$

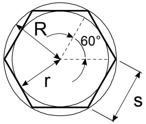
$$A = \frac{\pi d^2}{4} = 0.7854\, d^2$$

$C = 2\pi r = 6.2832r = 3.1416d$

$r = C \div 6.2832 = \sqrt{A \div 3.1416} = 0.564\sqrt{A}$

$d = C \div 3.1416 = \sqrt{A \div 0.7854} = 1.128\sqrt{A}$

REGULAR HEXAGON



A = area
R = radius of circumscribed circle
r = radius of inscribed circle
$A = 2.598S^2 = 2.598R^2 = 3.464r^2$
$R = S = 1.155r$
$r = 0.866S = 0.866R$

The construction of a regular hexagon forms six equilateral triangles,thus the area of the hexagon can also be found by calculating the area of the equilateral triangle and multiplying the result by six.

To convert		Multiply by
From	To	
hp Kw	kw hp	0.7457 1.3410
lbs/inch² Kpa	kPa lbs/inch²	6.8948 0.1450
m/min ft/min	ft/min m/min	3.2810 0.3048
inch mm	mm inch	25.4 0.03937
inch² cm²	cm² inch²	6.45 0.155
inch³ cm³	cm³ inch³	16.39 0.061
kg lbs	lbs kg	2.2046 0.4536
gallons litres	litres gallons	4.546 0.22

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